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Fabrication of Copper-Graphite MMCs Using Powder Metallurgy Technique

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ABSTRACT

Copper, and its, alloys and composites (being the matrix), are broadly used in the electronic as well as bearing materials due to the excellent thermal and electrical conductivities it has.

In this study, powder metallurgy technique was used for the production of copper graphite composite with three volume percent of graphite. Processing parameters selected is (900) °C sintering temperature and (90) minutes holding time for samples that were heated in an inert atmosphere (argon gas). Wear test results showed a pronounced improvement in wear resistance as the percent of graphite increased which acts as solid lubricant (where wear rate was decreased by about 88% as compared with pure Cu). Microhardness and compressive strength increased (about 8% and 16%, for each of them) and reached to the maximum values at 1% graphite percentage as compared with pure Cu, then it decreased after that critical graphite concentration. Microstructure test indicated that the dark region in the copper matrix was increased as the percent of graphite increased and the reinforcement particles were homogeneously distributed which means that the powder metallurgy technique is suitable for such task.

Keywords: metal matrix composite, powder metallurgy, mechanical properties, copper matrix composite.

تصنيع مادة النحاس المتراكب المدعم بحبيبات الكرافيت باستخدام تقنية تكنولوجيا المساحيق

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الخلاصة

النحاس وسبائكه ومركباته يستخدم بشكل واسع في المواد الالكترونية والمحامل الميكانيكية وذلك بسبب قابلية التوصيل الحراري والكهربائي التي يتمتع بها. في هذه الدراسة تم استخدام تقنية تكنولوجيا المساحيق لانتاج النحاس المتراكب المدعم بحبيبات الكرافيت. تم اختيار ظروف التشغيل وتمثلت بدرجة حرارة التلبيد حوالي 900 درجة مئوية مع زمن ابقاء حوالي 90 دقيقة داخل فرن كهربائي وسط حيز خامل مفرغ من الهواء (بوجود غاز الاركون). اظهرت نتائج الفحص تحسن ملحوظ في خاصية مقاومة البلى بزيادة نسبة حبيبات الكرافيت التي عملت كمادة مزيتة (حيث انخفض معدل البلى بنسبة بلغت 88% مقارنة بالمادة الاساس). اضافة الى تحسن في قيمة الصلادة ومقاومة الانضغاط (حيث حصلت زيادة بنسبة 8% و 16% لكل منهم مقارنة بالمادة الاساس)

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ووصلت لاعلى قيمة عند نسبة اضافة 1% من الكرافيت، بعد ذلك انخفضت هذه الخواص عند زيادة النسبة عن الحد الحرج. كما اشرت نتائج فحص البنية المجهرية ظهور مناطق غامقة في المادة المتراكبة الناتجة تزداد بزيادة نسبة الكرافيت، وقد ظهر واضحا التوزيع الحبيبي المتجانس للمادة الناتجة بشكل يعكس ملائمة استخدام تقنية تكنولجيا المساحيق في انتاج المادة اعلاه.

الكلمات الرئيسية:قالب مصفوفة معدني، علم مساحيق المعادن، خواص ميكانيكية، قالب مصفوقة النحاس

1. INTRODUCTION

Many of the recent technologies need special materials that have specific properties that cannot be fulfilled by the conventional polymers, metals or ceramics each alone. This particularly applies to the materials required for aerospace, transportation, and underwater applications. Airplanes engineers, for instance, are increasingly searching for structural components that are, corrosion, abrasion and impact resistant, strong, stiff as well as having low densities; this is somehow a formidable combination of characteristics. Normally, density increases with strength; therefore, increasing the stiffness or strength generally leads to a reduction in impact resistance, **Callister**, and **William**, **2003**.

A composite material is fabricated by combining two or more components to produce a novel bunch of properties, each of which retains its own distinctive characteristics. Most commonly, composites consist of two phases, the matrix (which is generally continuous, for example, metals, polymers, etc.) and reinforcement (which is in the form of fibers, and/or particles).

Advanced composites can be categorized into three basic groups: “Polymers Matrix Composites” (PMCs), “Ceramic Matrix Composites” (CMCs) and “Metal Matrix Composites” (MMCs). The last one combines both ceramic properties (high modulus and strength, possess bigger strength in shear and compression, in addition to high service temperature capabilities) with metallic properties (toughness and ductility), **Autar**, **2006**.

Copper-Graphite composites are an example of MMCs. It inherent the properties of Cu, i.e. high thermal and electrical conductivities, with those of graphite, i.e. low "thermal expansion coefficient" and solid lubricating. They are broadly used as bearing materials and brushes, due to the mentioned characteristics. Copper-graphite composite, with low percentages of the latter, is increasingly used to produce, connectors, "switches", slip rings, "relays", "plugs" and DC machines with high current and low voltage, **Pandey**, and **Awadh**, **2001**.

Hence, Copper Matrix Composites demonstrate a splendid combination of electrical conductivity and strength, while exhibiting, significant enhancement in mechanical and tribological properties, as well as others, such as high wear and corrosion resistant, and good hardness properties, while providing excellent lubricating specifications, due to the presence of graphite, **Chen**, **et al., 1996**.

In this study, powder metallurgy technique was implemented to fabricate Cu-graphite composite. This approach has many advantages over other methods, for example, the possibility of attaining uniform brushes and of decreasing or sometimes eliminating the tedious as well as costly machining procedures. On the other hand, there are some disadvantages in this technique related to the weak affinity for bonding between Cu and graphite particles, which increase the possibility of poor interfaces, which consequently gives undesirable effect on the structural, electrical and mechanical properties of the final product, **Orumwense, et al., 2001**. Tribologically, composite products depend on the matrix structure and the distribution of the reinforcement particles in it, **Nash, et al., 1995**.

Some researchers studied the fabrication of copper matrix composites using powder metallurgy, some of which are selected in the following:

Moustafa, et al., 2002, explained the effect of wear and friction characteristics on copper graphite composites fabricated with Copper "coated" and "uncoated" graphite particles**.** They found that the produced composite material has lower friction coefficient and wear rates than those fabricated from pure Cu, due to the smeared graphite film that forms at the specimen sliding surface that acts as a "solid lubricant". **Jaroslav, et al., 2008,** studied the effect of composition on the copper matrix coefficient of friction having (0–50 vol. %) of graphite particles to determine critical graphite-reinforcement percent above which the “coefficient of friction” stay almost constant and independent of composition, to be corresponding to the dynamic friction coefficient of the used graphite material whereas the wear rate decreases. Meanwhile the “coefficient of friction” can be lowered by having a more homogeneous distribution of graphite particles. **Yang, et al., 2010,** investigated the effect of pitch coke ratio on the mechanical and tribological properties of Cu–graphite composites**.** The addition of pitch coke to the matrix enhances the strength of bonding between the binder which is in this case binder (phenolic resin) and the carbon particles. The results exhibited that the friction coefficient of the copper–graphite composites micro-hardness, and bending strength rose as the pitch coke content increased. The more the content of pitch coke, the less become the wear rate of the resultant composites to reach a minimum point, after which, it increased. **Montasser, et al.**, **2010,** produced Copper matrix composites with reinforcement of graphite powders (2.5, 5, 7.5, and 10 wt. %) using powder metallurgy procedure. Influence of the processing parameters on the compression strength and the wear resistance of the fabricated composites was demonstrated. Three sintering temperatures (900, 950, and 1000 ^{o}C) and three "compaction pressures" (150, 250 and 350 MPa) were utilized. Zinc or lead with 0.5, 1 and 1.5 wt. % was mixed with (2.5 or 5 wt. %) copper graphite composites which gave high values of wear resistance, compressive strength, and hardness. **Bassam, 2015,** produced copper matrix composite (99% Cu +1% Graphite) and copper hybrid composite (99% Cu+1% Graphite) with different vol. % of alumina, via powder metallurgy technique. Effect of the addition of alumina on microstructure and mechanical properties were studied. Results of the hybrid composites showed significant improvement in the mechanical properties in comparison with Cu-graphite composite apparently due to the effect of two reinforcement elements.

In this work, the amount of graphite particles (reinforcements) that was mixed with the copper particles (matrix) was studied with respect to the mechanical properties (wear resistance, microhardness, compressive strength) of the resultant fabricated composite.

2. EXPERIMENTAL WORK

The matrix material that was used in the present work is commercially pure copper powder (average particle size is ~35 μm) produced by CDH /India. Graphite powder was used as a reinforcement material (average particle size is ~10 μm) procured from the same company. Copper and graphite powders were inspected at the Ministry of Science and Technology to verify their physical properties, the results are shown in **Table 1**.

The compacting dies were designed to accommodate the research requirements as well as to fulfill the “Dies Design Standards”. High-Speed Steel (HSS) was used as the raw material to manufacture the dies that were used to produce the wear, hardness and compression specimens, needed throughout this research work, the detailed design information of the die’s parts is shown in **Fig. 1**.

In this study, copper matrix composite reinforced with graphite powder was fabricated by powder metallurgy technique, with three different volume fractions of graphite (1%, 2% and 3%) all calculations were obtained by using the rule of mixture, The powder of samples blended together properly using a pestle and mortar for 30 minutes with the binder being 0.5ml (n-butanol) to ensure uniform distributions of the particles within the matrix and uniform mixing with binder, **Fig. 2**.

The blended samples were compacted through being cold pressed by applying a pressure of 39 bar on the 10mm diameter die, the pressing process was done by a hydraulic press having a capacity of (80 ton) manufactured by the German company (KNUTH), as shown in **Fig. 3**. The compressed samples were heated in an electrical furnace in the Materials laboratory / Engineering Technical College – Baghdad, at 900^{o} C and the soaking time was 90 min to remove the internal stresses and densify the compacted powder samples. The heating rate was 7 °C /min under an inert atmosphere (pure argon gas) at a flow rate of (2 liters/min), **Fig. 4** shows a sample after sintering.

Wear test specimens were fabricated according to ASTM G 99 – 04 standardizations, where their dimensions were (10× 20) mm. The experiments were carried out under, varying loads of (2.5, 5, 7.5, 10 and 12.5) N, constant speed of 1.178 m/sec (150 rpm) and a duration of 15 minutes for each test, as shown in **Fig. 5**. Microhardness testing of the samples was conducted using Zwick/Roell microhardness machine in the Central Office of Measurement and Quality Control in Baghdad, with a load of 200 g, in steps with 15 sec between each one according to (ASTM-E 384), **Fig. 6 a**. The compression test was carried out using a universal testing instrument (united test 300KN) at the Institute of Technology –Mechanical department, and according to ASTM E9-89a, **Fig. 6 b**.

Microstructures were performed using an optical microscope (MEIJI– Japan) with a digital camera to verify the homogeneity of the mixture and the presence of macro and micro-voids. All microscopic examinations were conducted at the Materials Laboratory of the Technical Engineering College – Baghdad.

3. RESULTS AND DISCUSSIONS

4. Wear Test

The wear resistance test was made on both, pure Cu and Cu-graphite composite samples. It was performed under dry conditions using a pin on disk arrangement. From the figure of wear resistance test results, it can be noticed, that in all tested materials, the intensity of wear rate rises as the applied load increase. The characteristic of that increase is not the same for all specimens depending on the percent of the reinforcement particles. The weight loss of each specimen after wear testing was taken in order to calculate the wear rate (gm/cm) of the samples.

Cu powder (matrix), was reinforced with graphite particles (reinforcement) with three percentages (1%, 2%, and 3%); the presence of these particles clearly affected the wear rate of the composite material. **Fig. 7** shows that the greater the fraction of the reinforcement particles (graphite) the higher wear resistance of samples (i.e. decrease in wear rate). Thus the fabricated composite showed improvement in average wear resistance as the graphite percentage increased, in comparison to the copper matrix. The main reason for this enhancement is due to the thickness increase of the smeared graphite film at the specimen sliding surface, this layer formed due to the extraction of graphite particles (during sliding) to the surface of the test pin, hence it acts as a "solid lubricant". Best homogeneity of graphite phase spatial distribution leads to lower friction coefficient of resultant composite or better wear properties. Moreover, the increasing of graphite percent leads to improvement in the graphite particles ability to adhere to the wear surface to generate solid self-lubricant layer (smeared graphite film) at the specimen sliding surface, so the metal-metal contacts are transformed into graphite film-metal contact or between two graphite layers, which consequently lead to lower friction, therefore the wear resistance of the fabricated composite improved in comparison with pure copper, **Chandana, 2012**.

3.2 Hardness

As mentioned before, the copper powders were mixed with graphite particles in three volume fractions (1%, 2%, and 3%). This addition improved the hardness property of the fabricated composite as compared with pure copper powders, where it reached maximum value of (67 Hv), at a percentage of about 1% , then it decreased, as shown in **Fig. 8**, which thought to be due to the wider spread of the agglomerated soft graphite after the critical concentration is reached. Another factor that could have to participate to enhance in the hardness initially is the effective "dispersion strengthening" by the introduction of graphite granules to the Cu matrix, **Bassam**, **2015**, and **Sibabrata** and **Abhijeet, 2012.**

3.3 Compressive Strength

Compression test was fulfilled on the fabricated composites to study the effect of the graphite addition on the compressive strength of the resultant composite. In this test, it was found that maximum compressive strength value (265.33 MPa) was reached at 1 % volume fraction of graphite because of the better dispersion of graphite particles in matrix forming pinning in the composite preventing grain growth hence increasing its strength. Then, compressive strength declined with the increase of the volume fraction of graphite particles, because more reinforcement particles (graphite content) leads to increases in the "brittleness" of the fabricated composites, which lead to fast failure and decrease in compressive strength. **Fig. 9** shows the relationship between the compressive strength and graphite particles content (in Cu matrix composites), **Bassam** , **2015** and **Sibabrata** and **Abhijeet, 2012.**

3.4 Microstructure

An optical microscope was used to study the distribution of reinforcement particles (graphite) in the matrix (copper).

Fig. 10, shows a homogeneous distribution of graphite powder (dark regions) in the copper matrix (white regions). Also, the distribution is true in the sense that at similar magnification, an increase in a number of dark regions can be seen with an increase in the percentage of graphite. Very less agglomeration is observed. There are few defects such as below holes, cavities, and cracks, gaps observed in the copper matrix.

5. CONCLUSIONS

The conclusions derived from this experimental work can be summarized as in the following:

1- Copper graphite composite with high mechanical properties and homogeneous particles distribution can be successfully fabricated by powder metallurgy using conventional sintering technique.

2- The "wear resistance" of the fabricated composite increases as the percentages of graphite particles increases, which acts as a solid lubricant. At 3% graphite, Wear resistance was improved by about 88% than for copper without additives.

3- Microhardness and compressive strength were enhanced at 1% graphite, after which it decreased as the graphite percent become higher. It was increased by about 8% and 16% respectively, at 1% graphite.

4- Microstructure inspection showed a uniform distribution, with an increase in dark regions as the percentage of graphite particles was raised.

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Table 1. Physical properties of material used.

Property	**Copper**	**Graphite**
Density (g/cm$^{3)}$	7.978	2.230
Purity %	99.99	99.5
Average particle size (µm)	~35	~10

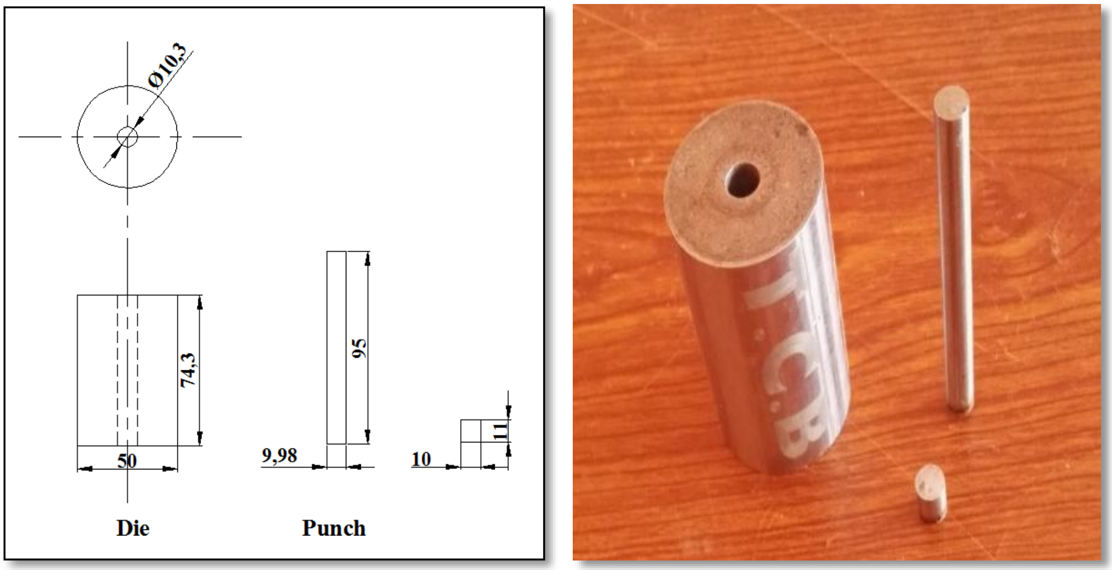

Figure 1. The Die and punch.

Figure 2. Blending process (Pestle and mortar).

Figure 3. Compaction process.

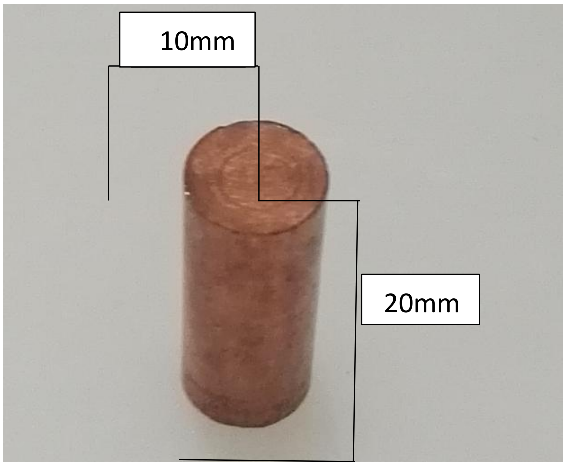

Figure 4. Sample after Sintering.

Figure 5. The pin on disc instrument**.**

(a) **(b)**

Figure 6. **(a)** Zwick/Roell microhardness machine, **(b)** Compression test device.

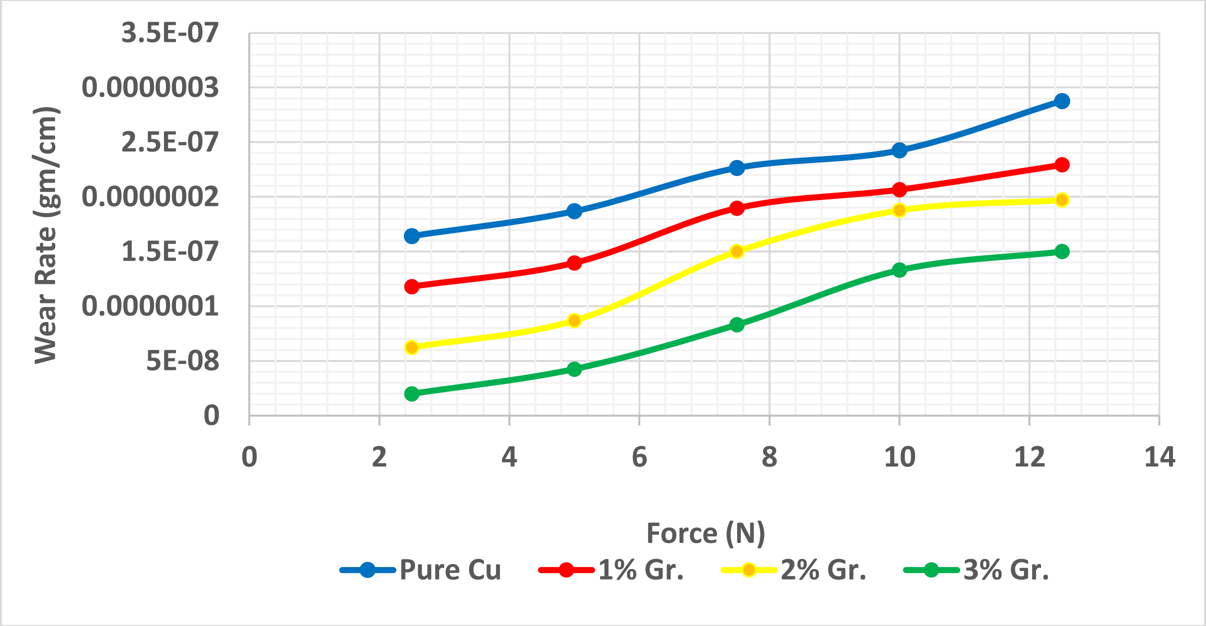

Figure 7. Comparison between wear rates of the fabricated composite (1%, 2%, and 3%) and pure Cu.

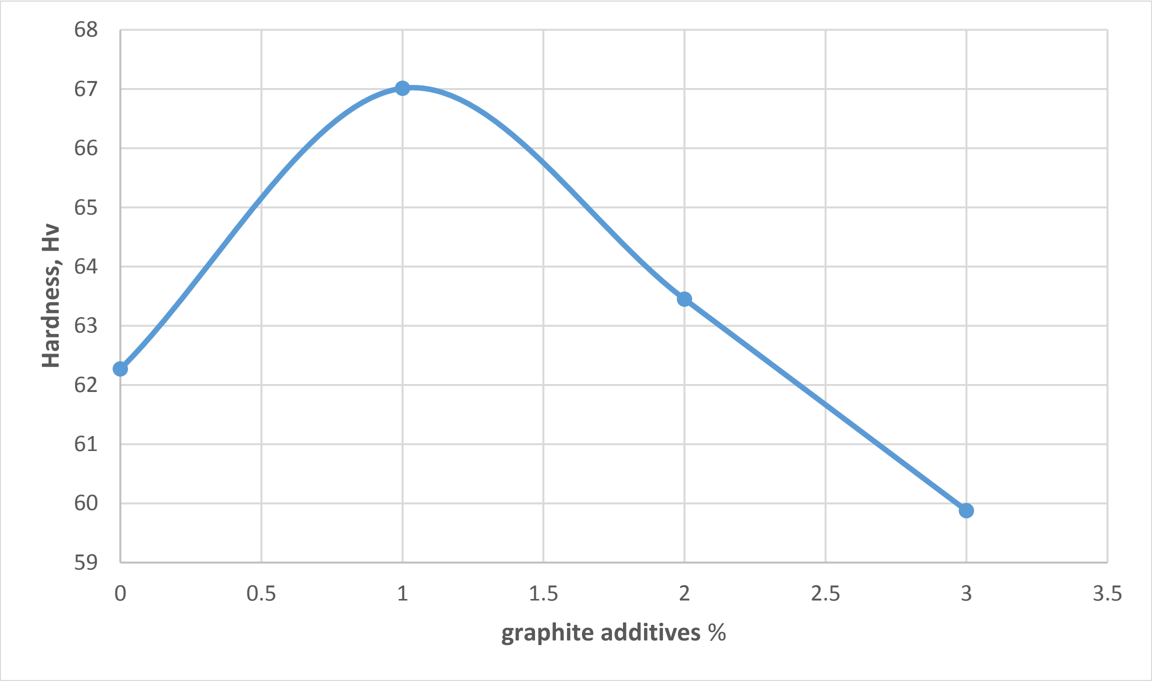

Figure 8. Variation in Vickers Hardness with graphite Vol. fraction.

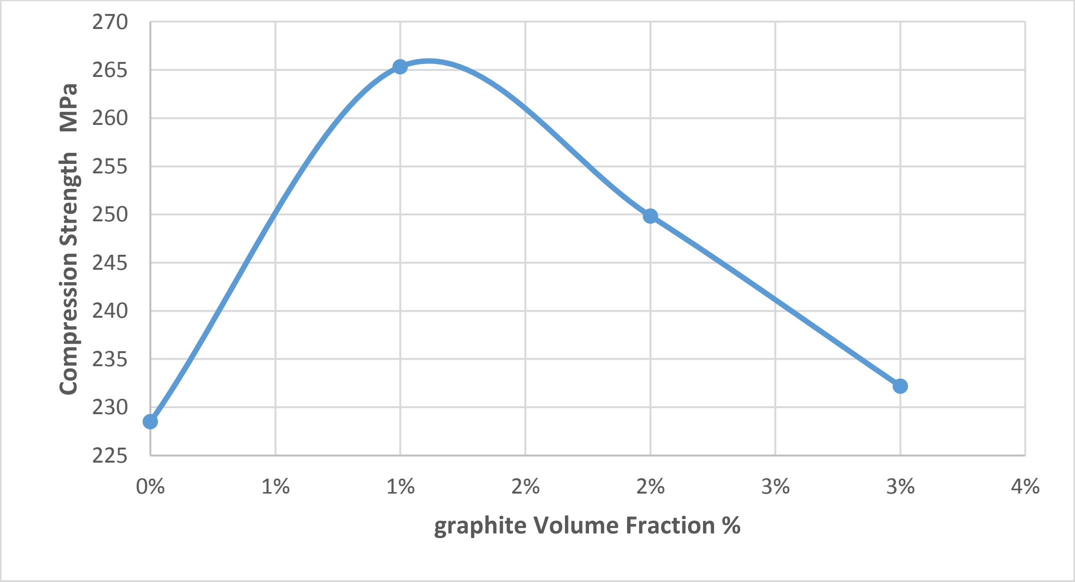

Figure 9. Compression strength of copper matrix composite reinforced with graphite at different volume fraction.

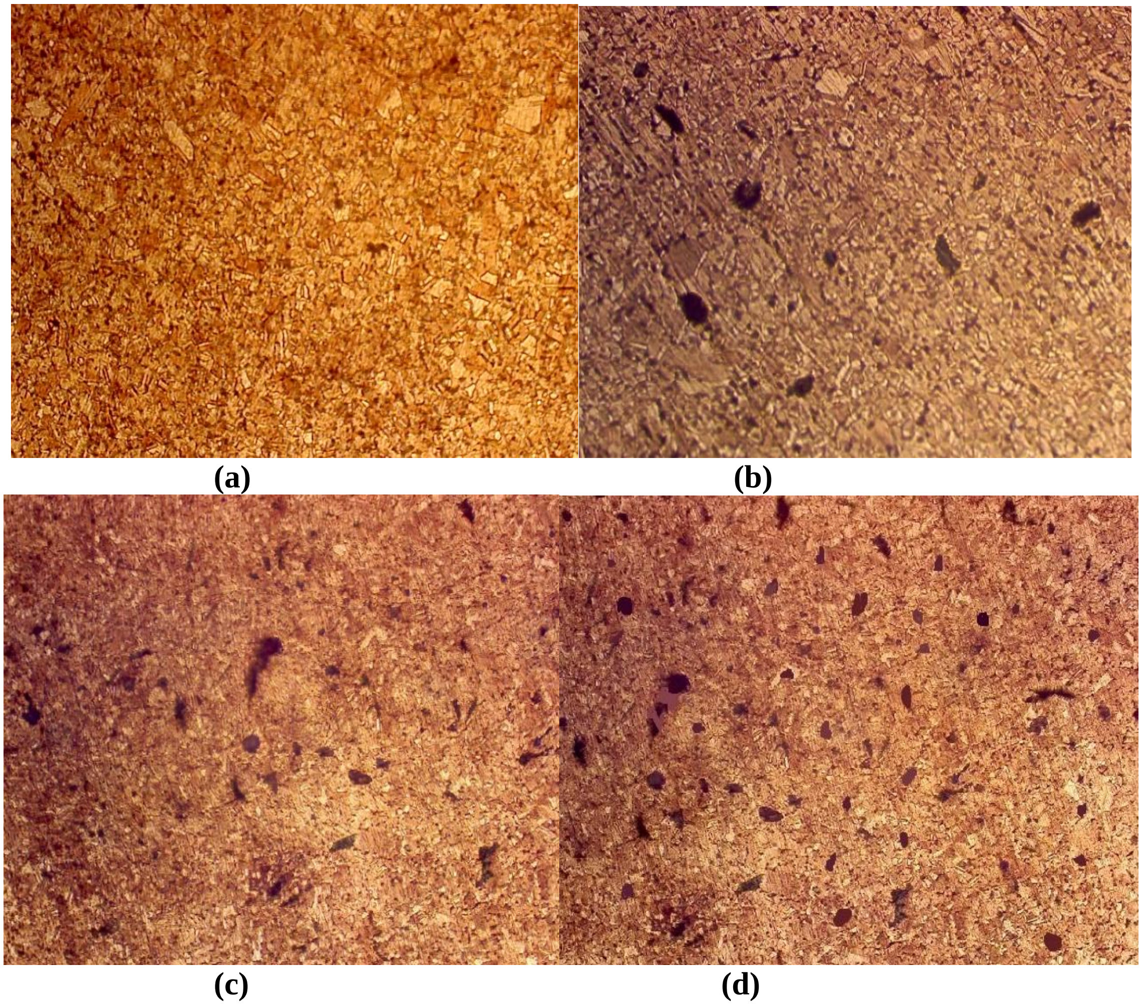

Figure 10. Optical photomicrograph (300 X) of: (a) pure Cu, (b) 99% Cu + 1% graphite, (c) 98% Cu + 2% graphite, 97% Cu + 3% graphite. (Dark region is the graphite particles while bright region is the copper).